Human Performance Enhancement for NATO Military Operations (Science, Technology, and Ethics)

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ABSTRACT

The United States' Office of Naval Research (ONR) is investigating a wide variety of methods to improve human performance. ONR's Force Health Protection program includes an emphasis on physically and psychologically prepared forces for enabling human performance enhancement. Efforts to develop psychological resilience are ongoing through identification of individuals at greatest risk for developing stress-based psychological disorders via personality and cognitive characteristics, identifying and understanding the features of the operational environment that contribute to stress-development (such as sleep-rest cycles, rules of engagement), and studying the traits of individuals who have successfully endured high-stress situations (such as SERE school). Training curricula and job placement based upon this knowledge will then be developed to imbue stress inoculation, improve performance in psychologically stressful environments, and reduce the risk of debilitating post-traumatic stress disorders.

Modelling and simulation (M&S) is also being used to enhance human performance by aiding in the design of equipment such as head-mounted devices for minimizing the effects of fatigue and strain, the design of light armor for maximum protection and range of movement, the design of better hearing protection and capability in high-noise environments and modelling the impact of human injuries on shipboard operations in casualty and threat situations.

Pharmaceutical interventions are also under development to facilitate human performance. Research on perfluorocarbons (PFCs) is in progress to increase dive performance envelope and reduce the risk of decompression sickness and arterial gas embolism. PFCs act as a "nitrogen sponge" and prevent bubbles from developing in the blood stream. It also appears that perfluorocarbons may provide some insulation from chest and head injury due to blast exposure if administered prior to insult by mitigating the inflammatory responses to cell damage. Pain management pharmaceuticals that increase pain tolerance without cognitive or sensorimotor sequelae are also under development. The delivery of encapsulated oxygen in the blood or intestines will enable the warfighter to effectively "store" oxygen for extended periods of operation in oxygen-deficient environments facilitating greater warfighters performance.

This combination of psychological, biochemical, M&S, and pharmaceutical approaches have provided a full range of opportunities to enhance human performance under Force Health Protection enabling the fielding of warfighters with great stress resiliency, highly-effective equipment and systems, and interventions for enhancing and protecting their performance and health.

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1.0 INTRODUCTION

The United States Navy recognizes that for optimal mission success we need to do far more than just to man the equipment, but rather to equip the man; to prepare the women and men of the Navy and Marine Corps for the physical and psychological stressors of their duties, and to sustain them during and after deployment. It is the mission of the United States' Office of Naval Research (ONR) to interact with the Fleet in order to identify gaps in the capabilities of the Navy to meet the needs of the Fleet. If a solution does not currently exist for meeting a Navy need, ONR will organize research programs to develop novel products that will fill these gaps. The Force Health Protection (FHP) Program within the Warfighter Performance Department of ONR has a portfolio of products currently under development that are designed to protect the physical and psychological health of deployed forces. Whenever possible, the products should enhance physical and mental capabilities, and maintain these warfighters at the peak of their abilities throughout deployment and for years to come despite the hardships of service. Current efforts to be presented here are FHP projects for reducing the risk or mitigating the impact of psychological stressors including post-traumatic stress disorder (PTSD); modelling and simulation to enhance personal protective equipment and to anticipate the impact of injuries on shipboard operations; and novel pharmacological approaches to protecting warfighters from hazardous conditions in extreme environments.

2.0 PRODUCTS

2.1 Neuropsychological Health Strategies

2.1.1 Development of Psychological Resilience through Stress Inoculation

The pre-deployment stress inoculation training (PRESIT) program will design, develop, and evaluate a stress mitigation system that will utilize virtual reality coupled with simulated scenarios to help deploying personnel better cope with combat-related stressors and mitigate the negative behavioral effects of trauma exposure. This leverages ongoing efforts at understanding the stress resiliency afforded by SERE (Survival, Evasion, Resistance, Escape) training and protective factors gleaned from asymptomatic combat veterans. Once a more rigorous inoculation regimen has been developed, the program will determine the most effective training for the warfighter. The focus of this preventative stress inoculation will be to minimize the non-functional (negative) aspects of combat stress, namely those symptoms typically associated with post-traumatic stress disorder (PTSD); conversely, the functional (positive) aspects of combat stress, including team cohesiveness and heightened situational awareness, will be experienced earlier and thus enable sailors and marines to quickly acclimate themselves to the combat environment more effectively.

Figure 1: Virtual reality presentations of simulated battlefield scenarios for stress inoculation training.

2.2 Modelling and Simulation Efforts

2.2.1 Personal Protective Equipment for Hearing Protection

Reduced hearing impacts survivability and effectiveness in the field. Noise-induced hearing loss is one of the most common disabilities among United States Sailors and Marines and has substantial human, economic and readiness impact. Noise-induced hearing loss is largely preventable by limiting exposure. However, once hearing loss occurs, there is currently no medical treatment to reverse it. In order to preserve hearing, ONR is developing the capability to capture ear canal shapes that can be digitally shared, archived, accessed, and manipulated for the design and manufacture of deep-insert custom earplugs, which are far better protectors than outer ear covers or shallow ear canal plugs. This approach will replace the material costs and man-hours of solid ear canal impression-taking with modern digital efficiency and accuracy to enhance the effectiveness of hearing protection. Deployed on-ship digital ear canal scanning will produce data files that can be managed as part of U.S. Navy personnel records, thus enhancing the manufacturing efficiency of custom earplugs. An additional component of this program will develop the capability to measure personal noise exposure that easily integrates into common styles of hearing protection devices. Data storage and retrieval will capture both daily and peak noise exposures with the goal of tailoring hearing protection selection, improved understanding of operational noise exposures and ensured quality of fit.

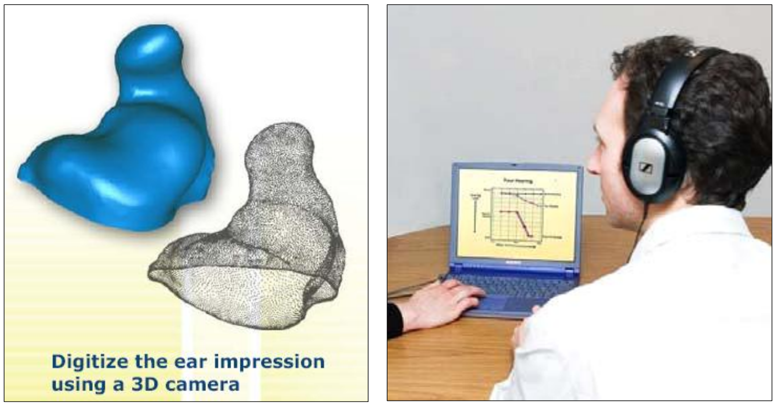

Figure 2: Digitally captured images of ear canal shapes.

2.2.2 Personal Protective Equipment for the Head and Neck

This effort will develop an integrated experimental human surrogate that will demonstrate the physical consequences of mechanical impact on the head, and relate it to pathophysiological changes of neural tissue. Since the relationship between kinetic input and resultant head injury cannot be described in simple cause-and-effect terms, this product will focus on the pressures and strains in compression, translation or rotation forces. This information has been represented in a finite element simulation of human spinal tissues (SPINE) and is currently being expanded to include a head/neck/brain complex to account for the impact of acceleration forces (crash and ejection) and blast (non-penetrating head/brain trauma). Additionally, the development effort for this product will produce an interactive hazard assessment tool that better relates bodily injury (from an anatomic perspective) to specific occupational disability that can be expected. These capabilities will then be applied toward the development of an informational (computational and physical) model with enhanced predictive capability that will be used to establish injury thresholds and assist in the design of protective equipment for warfighters and establish guidelines for equipment use.

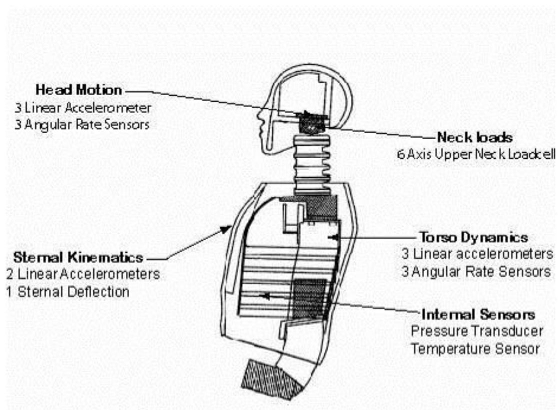

Figure 3: Modelling of head, neck, and spinal column to account for impact of acceleration and blast forces in the design of better personal protective equipment.

2.2.3 Modelling the Impact of Injuries on Shipboard Operations

The Human Injury and Treatment Model (HIT) will enable ship acquisition programs to assess ship performance in a range of casualty situations, including onboard personnel injuries and treatment capabilities. The resulting model will identify variation in personnel outcomes and ship effectiveness and recoverability resulting from proposed ship designs, manning and equipment configurations. Data derived from the model will support cost-benefit and return-on-investment assessments for medical equipment allowances, medical manning, automation augmentation of personnel, crew protection design features, etc. The data will also identify the capabilities required of shipboard mobile medical facilities. An integrated Navy approach for HIT assessments will ensure all aspects of shipboard injury and treatment are realistically addressed, including: the ability to locate injured personnel, transport them to shipboard treatment areas, provide life saving medical procedures, and/or evacuate personnel to shore-based facilities as well as the ship’s overall mission effectiveness in casualty situations.

2.3 Pharmacological Approaches for Protection in Extreme Environments

2.3.1 Pharmacology for Reducing the Risk of Decompression Sickness Injury

The development of intravenous perfluorocarbon (PFC) emulsions holds great promise as a treatment for decompression sickness (DCS) and arterial gas embolism (AGE). Based on time and depth of exposure, divers are at risk for DCS when they breathe inert gases during in-water transportation or when operational conditions do not allow the safe use of 100% O_2. Additional risk is anticipated in flying after diving and disabled submarine scenarios. When DCS occurs in remote areas, the U.S. Navy Diving Manual recommends considering measures such as in-water recompression when a chamber would not be available for 12 hours or longer. As a delay in recompression therapy is associated with worsened DCS outcomes and the risks for in-water decompression therapy are prohibitive, the need for effective adjunctive therapy is evident. The most promising candidate for adjunctive therapy is emulsified PFC. Two PFCs are being tested: Oxygent and dodecafluoropentan (DDFP). Their most valuable property for this use is that PFCs have an extremely high solubility for gases, thus acting as a "sponge" to hold in solution gases that would otherwise supersaturate the plasma and fall out of solution to form destructive intravascular bubbles. This product represents a multi-center design to address PFC use in DCS and AGE along with human safety studies in recompression therapy. The objective of this collaborative effort is to meet the necessary elements for U.S. Food and Drug Administration (FDA) approval of a PFC indication for DCS and AGE which will permit the operational use of PFC by the Fleet.

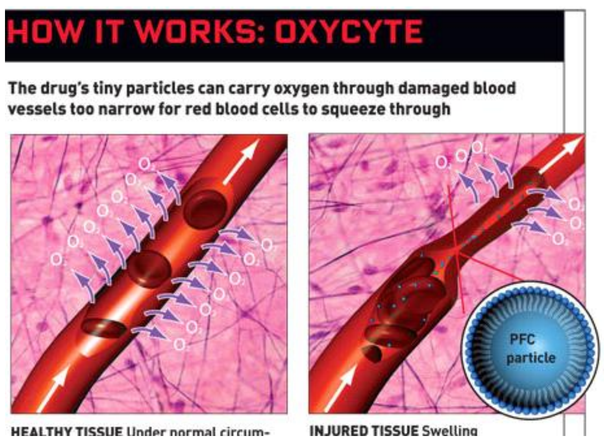

Figure 4: Perfluorocarbon emulsion in the reduction of risk or severity of decompression sickness.

2.3.3 Next-Generation Pain Management Pharmacology

The standard-of-care on the battlefield for control of pain is morphine. However, morphine has the serious side-effects of respiratory depression and sedation, along with the potential for abuse. Casualties who are given morphine must be disarmed and monitored, which then results in reduced tactical strength in the field. The technical approach taken by ONR was to develop a drug known as endomorphin-1 that is based on the naturally occurring pain-control compound in the human brain, but with fewer of the side effects of morphine. Endomorphin-1 proved to be rapidly metabolized. Subsequently, an analog of endomorphin-1 was developed that has similar analgesic qualities, but is longer-lasting; with tests showing benefits for 4 h or longer. This analog has been shown to be virtually identical to morphine as an analgesic, at a quarter of the pharmacological dose of morphine in a mouse model. There was no evidence that the mice found the

endomorphin analog rewarding, in contrast to morphine, indicating that there is lower potential for abuse. The objective of the work remaining is to determine the effect of the drug on cognitive functioning.

2.3.4 Non-Pulmonary Oxygenation

The objective of this program is to develop a replacement non-pulmonary (casualty breathing not required) oxygenation strategy for use in traumatic shock, wounds, and other injuries. Hydrogen peroxide (H_2O_2) would be stored in microcapsules and injected into the blood where enzymes would break the H_2O_2 down into O_2 and water. Some calculations of the amount of O_2 that could be delivered by this approach indicated that a single injection treatment would produce and deliver enough oxygen to supply the majority of the metabolic needs of the body for at least one hour in the case of traumatic shock or potentially in oxygen-scarce extreme environments such as at altitude and under water. This concept is being further developed to use the H_2O_2 system in a mechanical device for creating a point-of-use low-pressure O_2 generator that is more portable and sustainable than high-pressure cylinders of compressed O_2.

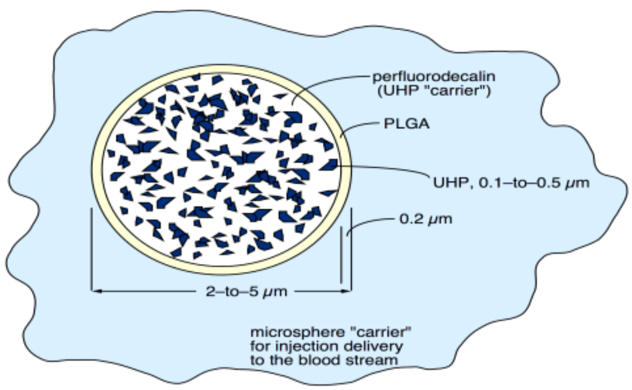

Figure 5: Schematic of a hydrogen peroxide delivery microcapsule. The poly(lactide-co-glycolide polymer microcapsule contains 100-500 nm urea hydrogen peroxide particles suspended in a biocompatible perfluorocarbon. The microcapsule shell is a 0.2 μm thick membrane.

3.0 CONCLUSIONS

The Force Health Protection Program's neuropsychological, modelling and simulation, and pharmaceutical approaches have provided a range of opportunities to protect, enhance, and maintain the health and performance of our warfighters. The ongoing Human Performance Optimization efforts at ONR strive to increase psychological stress resistance, provide improved personal protective equipment to increase performance and preserve effectiveness and functionality, and maintain performance in a variety of extreme environments. ONR aims to provide products that will send warfighters into the field with greater resiliency to the physical and mental stresses of their missions.